Experimental Analysis of Solar Based Flat Plate Collector

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Abstract— This paper describes the performance analysis of solar based flat plate collector. Flat plate collector (FPC) is widely to heat water in the home for bathing, washing and heating, and can even be used to heat outdoor swimming pools and hot tubs. The Flat plate collector (FPC) is a kind of a heat exchanger which transforms solar radiation into heat energy which is then used to transfer the heat to the Fluid flowing through the pipe. The system is designed with dimensions 100*100cm in such a way the water flows from inlet to outlet through pipe of length as 14m with the serpentine configuration in order to have a steady flow of water through the pipe. The water flows through the pipe by natural circulation. The main components of FPC are Absorber Plate, Glazing Cover and Thermal Insulation. The aim of this study is to evaluate the optimum mass flow rate of water at the efficiency is maximum. The efficiency of the FPC decreases with an increase in mass flow rate of water. The test was conducted for three flow rates 0.5L/min, 1L/min and 1.5L/min. It was found out that the maximum efficiency is when the fluid flows at the rate of L/min because if the fluid flows slower then it gets more time to absorb the heat. A test setup is fabricated and experiments conducted to study these aspects under laboratory conditions.

Keywords: Flat plate collector, Efficiency of collector, optimum mass flow rate, solar energy

Nomenclature:

HTF –Heat transfer fluid
FPC-Flat Plate collector
Q_i –Total Heat incident, W
A_c – Area of Collector, m^2
Q_u –Total Heat Received, W
T_i- Inlet Temperature, °C
T_o- Outlet temperature, °C
C_p- Specific heat capacity, KJ/Kg-K
U_e-Edge loss Coefficient, W/m^2-°C
m- Mass flow rate, Kg/sec
U_L- Overall heat loss coefficient, W/m^2-°C
T_m- Mean Temperature of Plate, °C
T_a-Ambient temperature, °C
DNI-Direct normal irradiance, W/m^2
U_t-Top loss coefficient, W/m^2-°C
U_b-Bottom loss Coefficient, W/m^2-°C
ΔT- Temperature difference between inlet and outlet

I. Introduction

Solar energy is the most abundant energy resource on Earth. It can be captured and used in several ways, and as a renewable energy source, is an important part of our clean energy future. Solar power can be harnessed and converted to usable energy using photovoltaics or solar thermal collectors. Solar is a clean, renewable energy resource, and figures to play an important part in the global energy future

The project is conducted to achieve two objectives that is to find out the mass flow rate of the Heat transfer fluid (HTF) at which the efficiency and effectiveness of the collector is maximum and to reduce the cost of the collector.

There are three general types of solar thermal energy used: low-temperature, used for heating and cooling; mid-temperature, used for heating water; and high-temperature, used for electrical power generation.

Low-temperature solar thermal energy systems involve heating and cooling air as a means of climate control. An example of this type of solar energy usage is in passive solar building design. In properties built for passive solar energy use, the sun’s rays are allowed into a living space to heat an area and blocked when the area needs to be cooled.

Mid-temperature solar thermal energy systems include solar hot water heating systems. In a solar hot water setup, heat from the sun is captured by collectors on your rooftop. This heat is then transferred to the water running through your home’s piping so you don’t have to rely on traditional water heating methods, such as water heaters powered with oil or gas.

High-temperature solar thermal energy systems are used for generating electricity on a larger scale. In a solar thermal electricity plant, mirrors focus the sun’s rays on tubes containing a liquid that can hold heat energy well. This heated fluid can then be used to turn water into steam, which then can turn a turbine and generate electricity. This type of technology is often referred to as concentrated solar power. Stephan Fischer and Erich Hahne [1] Explained the efficiency of solar collectors and they have also Explained the importance of Glazing cover in improving the thermal efficiency of solar collectors. Sunil K. Amrutkar, Satyshree Ghodke, Dr. K. N. Patil [2] evaluated the performance of FPC with different geometric configurations. The characteristics of the glazing materials are Reflectance (ρ), Absorptivity (α) and transmittance (τ). Walaa Mousa Hashima, Ali Talib Shomranb, Hasan Ali Jurmutb [3] Discussed about the dependency of efficiency of the FPC on the mass flow rate of the heat transfer fluid. The efficiency of the FPC increases with the decrease in mass flow rate of the Heat transfer Fluid. Y. Raja Sekhar, K. V. Sharma and M. Basaveswara Rao [4] evaluated the Top loss coefficients in solar Flat Plate collector. The collector efficiency is dependent on the temperature of the plate which in turn is dependent on the nature of flow of fluid inside the tube, Thermal Insulation, ambient temperature, top loss coefficient, the emissivity of the plate and glass cover, slope, etc. Daniela MILOSTEAN, Mihaela FLORI [5] provided an overview, using information from the literature, on the technical solutions developed by the researchers, in order to increase the thermal efficiency of the flat-plate solar collectors. The glazing is a transparent cover that has two important functions: first is to reduce the convection losses from the absorber plate and the second is to reduce the radiation losses from the collector because the glass allows the passage of sort wave radiation from the sun, but does not allow long-wave thermal radiation emitted from the absorber plate to pass outside the collector glazing.

II. METHODOLOGY

A. *Selection of glazing cover*

A body which allows the heat radiation to pass through is called as Diathermanous body For Example-quartz, hydrogen etc. Glazing cover is basically defined by three main properties namely reflection (ρ), transmission (τ) and absorption (α).For the maximum efficiency transmission should be maximum. According to the law of conservation of energy $\alpha+\rho+\tau=1$. Absorption (α) is defined as the fraction of the total solar energy absorbed by the substance. Reflection (ρ) is defined as the fraction of the total solar energy reflected by the substance. Transmission (τ) is defined as the fraction of the total solar energy transmitted by the substance. For the collector to have maximum efficiency the transmission value of the glazing cover should be maximum. The main purpose of the glazing cover is to trap as much as solar radiation possible and to reduce the upward losses as well. It serves as a shield. There are many materials available which can be used as the glazing cover. The selection of the material for the glazing cover depends on transmission value, Durability, strength. Glazing cover traps the short-wave radiation and do not let the long wave radiation emitted by the collector to go out. Glass is the most common material used. Plastics can also be used as the glazing cover but it has a limitation of the maximum temperature it can withstand. In order to serve as a heat trap glazing cover also reduce the upward losses.

S.no.	Materials	Transmittance (τ)
01	Crystal Glass	0.91
02	Window Glass	0.85
03	Polyamide (Kapton)	0.96
04	Fluorinated ethylene propylene	0.80

Table 1: Transmittance values of various Glazing materials

We have Selected Window Glass for the Glazing cover as the transmittance value is good enough to serve as a heat trap.

B. *Absorber Plate*

Absorber plate is used to absorb as much as possible radiation from the sun and to reduce the upward losses as well. Absorber plate should be such that it reduces the re-emission. Absorber plate absorbs the solar radiation and then transfers those heat to the circulating heat transfer fluid (HTF). The Main characteristics of the absorber plate are Thermal conductivity, Durability and cost. The selection of the absorber plate depends on these three factors only. Coating of the absorber plate is also done to improve the solar absorptance value. Usually black paint is preferred for the coating as it has an Absorptance (α) value ranging between 0.91 to 0.97.

S.no.	Surfaces	Absorptance (α)	Reflectance (ρ)
01	Black paint	0.96	0.04
02	Grey Paint	0.75	0.25
03	Galvanized Steel	0.65	0.35
04	Aluminum Foil	0.15	0.75

Table 2: Solar Absorptance and reflectance value for various surfaces

C. *Thermal Insulation*

Flat Plate Collector (FPC) must be insulated through the back and side to prevent the convection and conduction losses. Usually Glass wool and thermocol is recommended of thickness 4cm at the bottom and 3cm at the side of the collector box.

S.no	Insulating Material	Maximum allowable temperature (°C)	Density (kg/m^3)	Conductivity (W/m-K at 20°C)
01	Mineral wool	>200	60 – 200	0.040
02	Glass wool	>200	30 – 100	0.040
03	Polyurethane foam	<130	30 – 80	0.030
04	Thermocol	<80	20 – 30	0.0314

Table 3 Thermal Conductivity of various Thermal Insulators

III. MODELING OF FLAT PLATE COLLECTOR (FPC)

In this work we have assumed the steady flow of Heat transfer fluid (HTF) and thus the mathematical equations are-

Total Heat Incident upon the Collector is given by-

$Q_i = DNI*A_c$ (1)

Heat Received by the collector is given by-

$Q_u = A_c*\{Q_i-U_L\{T_m-T_a\}\}$ (2)

Total Loss coefficient is given by-

$U_L=U_t+U_b+$ (3)

$U_b= .01*U_t$ (4)

$U_e \cong U_b$

Mean Temperature of the HTF is given by-

$T_m= (T_o+T_i)/2$ (5)

$(\Delta T)_{ideal}= T_m-T_a$ (6)

Mass Flow rate of the HTF is given by-

$m= Q_i / (C_p*\Delta T)$ (7)

The collector efficiency is given by the equation-

$\eta= \Delta T_{actual}/\Delta T_{ideal}$ (8)

IV. EXPERIMENTAL SETUP

The Collector was designed in a square shape of dimensions 100*100cm with the maximum height at one side being 20cm and minimum height is 10cm keeping angle of tilt at 28°.The serpentine configuration is adopted for pipe of length 14m and diameter 10mm so as to keep the flow of Heat transfer fluid (HTF) steady. The Absorber plate is covered with a Glass of thickness 6mm so as to trap the heat and to reduce the upward losses. Thermal Insulation Thermocol of thermal conductivity 0.04 W/m-K is used with thickness 4cm at the side and 3cm at the bottom of the collector box to reduce the conduction and convection losses. Two thermocouple has been connected at the inlet and outlet pipe. Absorber plate is made up of aluminum and is coated with a black paint (α=0.95). Pipe is made up of copper as its thermal conductivity is 401 W/m*K.

Fig. 1: Experimental setup shows serpentine configuration of pipe

S.no.	Component	Dimensions
01	Length of Collector (cm)	100
02	Area Of collector (cm^2)	100*100
03	Width of collector (cm)	100
04	Thickness of collector (cm)	10
05	Thickness of absorber plate (cm)	0.2
06	Copper Tube Diameter (cm)	1
07	Copper Tube Thickness (cm)	0.1
08	Tube overall length (cm)	1400
09	HTF	Water
10	Insulation thickness at bottom (cm)	4
11	Insulation Thickness at side (cm)	3
12	Glazing Cover Thickness (cm)	0.6

Table 4: specifications of Flat Plate Collector (FPC)

V. RESULTS AND DISCUSSION

Renewable energy is energy produced from sources that do not deplete or can be replenished within a human's life time. The most common examples include wind, solar, geothermal, biomass, and hydropower. This is in contrast to non-renewable sources such as fossil fuels. The collector is fabricated to evaluate the variation of efficiency with different flow rates and to find the optimum mass flow rate. The readings have been taken from 9 at the morning to 2 in the afternoon. The maximum temperature occurs in the half day because of the maximum solar radiation. In this test water was taken as the only HTF and parameters was evaluated at the three different flow rates 0.5L/min, 1L/min and 1.5L/min. Figure 2 shows the outlet temperature at the flow rates 0.5L/min, 1L/min and 1.5L/min. Figure 2 shows that the maximum temperature in the half day. The maximum temperature encountered in case of flow rates 0.5L/min, 1L/min, 1.5L/min is 55°C, 49°C and 45°C. This clearly shows that as the flow rates increases efficiency decreases as if fluid flows at a higher rate then it gets less time to absorb the heat and hence the efficiency decreases.

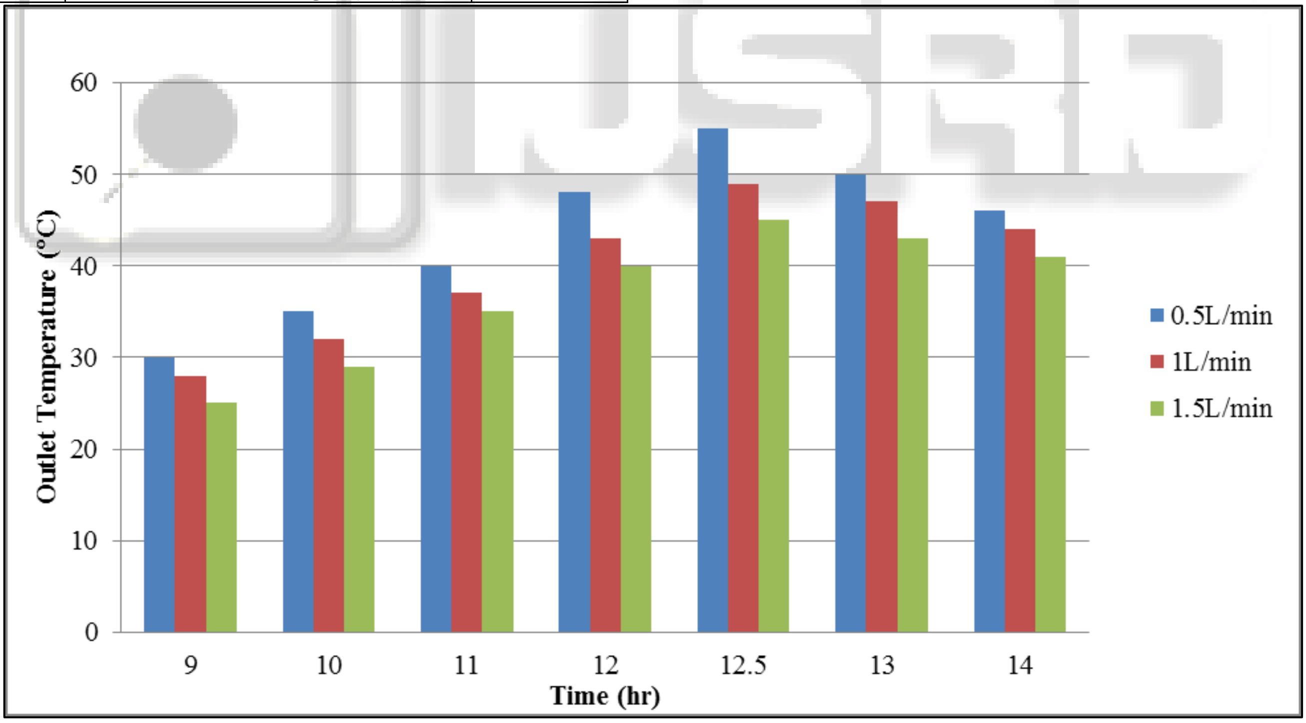

Fig. 2: Compare between outlet temperature at flow rates 0.5L/min ,1L/min and 1.5L/min

From Figure 2 it is clear that the Outlet Temperature ranges between 55°C to 28°C. Figure 3 indicates the variation of efficiency with different mass flow rate 0.5L/min, 1L/min and 1.5L/min. Maximum Efficiency is encountered in case of 0.5L/min. The test was conducted under the same conditions but with different flow rates. From Figure 3 it is clear that the efficiency ranges from 55% to 36% and the maximum efficiency is encountered in 0.5L/min flow rate.

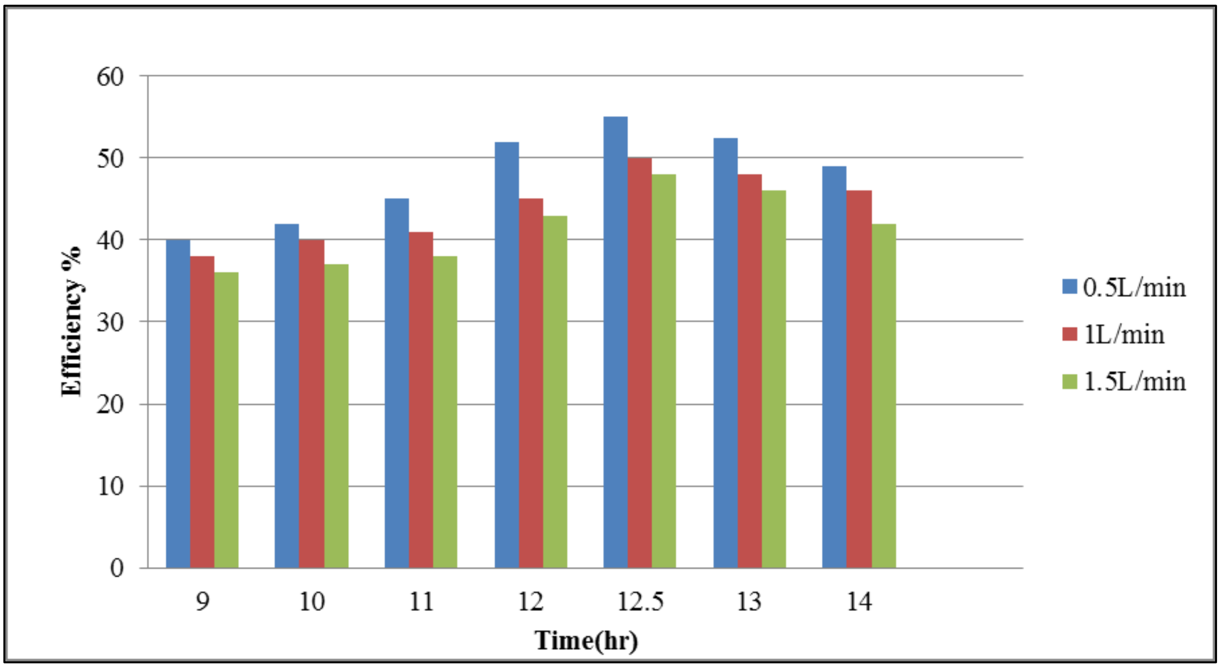

Fig. 3: Variation of efficiency with Different flow rates

VI. CONCLUSIONS

From the above comparison it can be concluded that there are variations in efficiency of the collector with the variation in the flow rate of water. The graph presented above clearly shows that water at flow rate 0.5L/min absorbs more heat than the water at flow rate 1L/min and 1.5L/min. The efficiency of the collector ranges between 55% to 38%. Angle of tilt is kept at 28° in order to absorb more and more solar radiation. The collector has been designed and fabricated keeping in mind the cost factor so instead of having tracking collector which would have certainly increased the cost 2 to 3 times an angle of tilt was calculated. Further it can be concluded on the basis of the result obtained above that the experiment was performed under clear sky conditions and If flow rates of the fluid decreases then efficiency increases as if the fluid flows at a slower rate then it gets more time to absorb the heat.

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